HORIZONTAL WELLBORE PRESSURE MEASUREMENT

Inventor: Kenneth L. Perales

CROSS-REFERENCE TO RELATED APPLICATION

The present application claims the benefit under 35 USC §119 of the filing date of prior PCT application serial no. PCT/US02/26340, filed August 19, 2002, the disclosure of which is incorporated herein by this reference.

BACKGROUND

The present invention relates generally to operations performed and equipment utilized in conjunction with subterranean wells and, in embodiments described herein, more particularly provides systems and methods for measuring pressure in wells.

One method known to those skilled in the art of measuring pressure in a well is to position a chamber in the well at a location where the pressure measurement is desired. The chamber is open at its bottom end. A line, sometimes referred to as a "capillary tube" is connected to the chamber at its upper end.

A gas is introduced into the line and the chamber in order to balance pressure in the well fluid at the chamber. Typically, this is accomplished after the chamber is positioned in the well, by flowing the gas under pressure from the surface through the line and into the chamber. A measurement of the pressure in the gas at the surface when the gas pressure balances the pressure in the well fluid at the chamber is then used to calculate the well fluid pressure.

In order for this method to perform well, the chamber should be at least partially filled with the gas at all variations of well fluid pressures expected. The well fluid should not be permitted to enter the line extending to the surface, since this would alter the theoretical basis for the pressure calculation, and would potentially lead to plugging of the line. For these reasons, this method is typically not used in wellbores having greater than about 60° deviation from vertical, and this method is generally considered unusable in wellbores having greater than about 70° deviation from vertical.

Therefore, it will be readily appreciated that improved methods and systems are needed for measuring pressure in highly deviated or horizontal wellbores. These systems and methods would also be useful in relatively vertical wellbores.

SUMMARY

In carrying out the principles of the present invention, in accordance with embodiments thereof, pressure measurement systems and methods are provided which solve the above problems in the art.

In one aspect of the invention, a method of measuring pressure in a subterranean well is provided. The method includes the steps of: providing a pressure measurement apparatus including a generally tubular mandrel having a tube wrapped helically externally about the mandrel; interconnecting the mandrel in a tubular string, a flow passage of the tubular string extending

longitudinally through the mandrel; connecting the tube to a fluid line extending to a remote location; positioning the tubular string in the well; displacing a predetermined fluid through the line and the tube; and measuring pressure in the fluid at the remote location.

In another aspect of the invention, another method of measuring pressure in a subterranean well is provided. The method includes the steps of: providing a pressure measurement apparatus including a fluid flowpath; connecting the flowpath to a fluid line extending to a remote location; positioning the apparatus in the well, so that the flowpath extends in alternating at least partially vertical directions; displacing a predetermined fluid through the line and the flowpath; and measuring pressure in the fluid at the remote location.

In yet another aspect of the invention, a system for measuring pressure in a subterranean well is provided. The system includes an apparatus interconnected in a tubular string in the well. The apparatus includes a generally tubular mandrel, and a flowpath extending helically externally about the mandrel. A flow passage of the tubular string extends longitudinally through the mandrel.

A line is connected to the flowpath and extends to a remote location. Pressure applied to a predetermined fluid in the line at the remote location balances pressure in well fluid admitted into the flowpath.

In a further aspect of the invention, another system for measuring pressure in a subterranean well is provided. The system includes a pressure measurement apparatus including a fluid flowpath. A fluid line is connected to the flowpath and extends to a remote location.

The apparatus is positioned in the well, so that the flowpath extends alternately upward and downward. A predetermined fluid is displaced through the line and into the flowpath.

These and other features, advantages, benefits and objects of the present invention will become apparent to one of ordinary skill in the art upon careful

consideration of the detailed description of representative embodiments of the invention hereinbelow and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1-3 (Prior Art) are schematic cross-sectional views of a prior art pressure measurement method;

FIG. 4 is a partially cross-sectional view of a first pressure measurement apparatus embodying principles of the present invention;

FIG. 5 is a schematic partially cross-sectional view of a second pressure measurement apparatus embodying principles of the present invention;

FIG. 6 is a schematic partially cross-sectional view of a third pressure measurement apparatus embodying principles of the present invention;

FIG. 7 is a schematic cross-sectional view of a first pressure measurement method using the apparatus of FIGS. 4-6, the method embodying principles of the present invention;

FIGS. 8-10 are alternate embodiments of tubes which may be used in the apparatus of FIGS. 4 & 5; and

FIG. 11 is a schematic cross-sectional view of a second pressure measurement method using the apparatus of FIGS. 4-6, the method embodying principles of the present invention.

DETAILED DESCRIPTION

Illustrated in FIGS. 1-3 is a prior art method 10 of measuring pressure in a wellbore 14. In the method 10, a chamber 12 is lowered into the wellbore 14

connected to a line 16. A pressurized gas 18 is then forced down the line 16 and into the chamber 12, displacing well fluid 20 out of the chamber 12.

In FIG. 1, the method 10 is depicted after the well fluid 20 has been displaced completely out of the chamber 12. At this point, pressure in the gas 18 balances pressure in the well fluid 20 at the chamber 12. If pressure in the well fluid 20 increases, the gas 18 will be compressed, and the well fluid will enter the chamber 12 as depicted in FIG. 2. Since the pressure in the gas 18 continues to balance pressure in the well fluid 20, this increase in pressure in the well fluid can be detected by monitoring the pressure in the gas 18 via the line 16, which extends to a remote location, for example, to the earth's surface. This type of pressure measurement is described in U.S. Patent No. 4,010,642, the entire disclosure of which is incorporated herein by this reference.

The method 10 performs well in substantially vertical wellbores, such as the wellbore 14 depicted in FIGS. 1 & 2. However, if the chamber 12 is positioned in a wellbore 22 which is horizontal or at least substantially deviated from vertical, as depicted in FIG. 3, serious problems develop in the method 10. For example, the usable volume of the chamber 12 is significantly reduced, which substantially limits the range of pressures in the well fluid 20 which may be measured using the method 10. As another example, there is the danger that the well fluid 20 will enter the line 16, plugging the line and requiring replacement, or at least retrieval and cleaning, of the line at substantial expense.

It is generally considered that the method 10 cannot be used in wellbores which are deviated from vertical greater than about 70°. Significant problems may be experienced when the method 10 is used in wellbores deviated greater than about 60°. As used herein, the term "substantially deviated" is used to describe wellbores which are deviated greater than about 50° from vertical.

It has become increasingly common for wellbores to be drilled horizontally and at other substantial deviations from vertical. The method 10 is largely unsuitable for use in these wellbores, and so there is a need for an improved method of measuring pressure in substantially deviated wellbores. Some

wellbores are even drilled past horizontal, that is, the wellbores incline upward in the direction in which they are drilled. It will be appreciated that the method 10 is completely unusable in these wellbores drilled past horizontal, since the chamber 12 would fill with well fluid 20, and well fluid would enter the line 16.

Representatively illustrated in FIG. 4 is a pressure measurement apparatus 30 which embodies principles of the present invention. The apparatus 30 may be used in place of the chamber 12 in the method 10. Of course, the apparatus 30 may be used in other methods in keeping with the principles of the invention.

In the following description of the apparatus 30 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper", "lower", etc., are used only for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., and in various configurations, without departing from the principles of the present invention.

The apparatus 30 includes a generally tubular mandrel 32 which is configured for interconnection in a tubular string, such as the tubing string 15 described in the incorporated U.S. Patent No. 4,010,642. The apparatus 30 further includes a tube 34 which is coiled (that is, wrapped helically) about the mandrel 32. The tube 34 is connected at its upper end 36 to a smaller diameter line 38 which extends to a remote location, such as the earth's surface or another location in the well.

Since the tube 34 serves as a volumetric fluid chamber in the well, the tube preferably has a large internal cross-sectional flow area, larger than that of the tube 38. Increasing the cross-sectional area of the tube 34 permits its length to be decreased for a given desired volume, but of course, the size of the tube is constrained by the practical limits of its use in a particular wellbore.

A lower end 40 of the tube 34 is open to the wellbore external to the mandrel 32 when the apparatus 30 is positioned in the wellbore. Alternatively,

the lower end 40 of the tube 34 could be routed so that it is in fluid communication with a flow passage 42 formed longitudinally through the mandrel 32, if it is desired to monitor pressure of well fluid in the flow passage.

The apparatus 30 is depicted in FIG. 4 in a horizontal position, which represents its use in a substantially deviated wellbore, so that it may be more readily appreciated how the apparatus solves the problems in the art described above. In actual use, the apparatus 30 is interconnected in a tubular string, such as a production tubing string, segmented or coiled tubing, etc., and positioned in a wellbore. A predetermined fluid 46, such as helium or nitrogen gas, or a liquid, such as silicone oil, is flowed under pressure from a remote location, through the line 38, and into the tube 34. Any well fluid which entered the tube 34 while the apparatus 30 was being positioned in the wellbore would be displaced out of the lower end 40 of the tube.

Note that, at this point, even though the apparatus 30 is positioned in a substantially deviated wellbore, well fluid does not fill a significant portion of the tube 34, as was the case in the method 10 depicted in FIG. 3. Instead, some well fluid may enter the lower end 40 of the tube 34 and fill a first somewhat vertical coil or wrap 44 of the tube, but the well fluid will not advance further into the tube. This due to the fact that, in order to advance further into the tube 34, the well fluid would have to flow uphill against the force of gravity, and pressure in the predetermined fluid 46 balances pressure in the well fluid.

As pressure increases in the well fluid at the apparatus 30, or if some of the predetermined fluid 46 in the line 38 and tube 34 is released, the well fluid is permitted to advance further into the tube. However, the well fluid will again only be permitted to advance into the tube 34 a distance sufficient to compress the predetermined fluid 46 in the tube, so that the pressures in the predetermined fluid and the well fluid are balanced.

If pressure in the well fluid then decreases, the well fluid will be forced back out of the tube 34 by the pressure in the predetermined fluid 46, until the pressures in the fluids are again balanced. Some small portion of the well fluid

may remain in lower arcs of the tube 34, but this will not significantly reduce the usable volume of the tube.

Although the apparatus 30 is depicted in FIG. 4 as having the tube 34 wrapped about the tubular mandrel 32 for interconnection in a tubular string in a well, so that the flow passage 42 also extends through the tubular string, it will be readily appreciated that the principles of the invention may be incorporated into an apparatus which is conveyed on wireline, on coiled tubing, on the line 38, etc. Thus, it is to be clearly understood that the principles of the invention are not limited to the specific details of the apparatus 30 described above, but instead may be applied to a wide variety of situations.

One important aspect of the usefulness of the apparatus 30 is that the coils 44 of the tube 34 are oriented in alternating at least partially vertical directions when the apparatus is positioned in a sufficiently deviated wellbore. Thus, a flowpath 48 formed through the tube 34 extends alternately upward and downward along the length of the tube. This forces the well fluid to overcome the force of gravity in order to flow from one coil 44 to the next.

Other flowpath configurations may be used to achieve this advantage of the apparatus 30 and methods incorporating such apparatus. Furthermore, flowpaths formed in elements other than tubes may be used, in keeping with the principles of the invention. Additional embodiments of the invention schematically depicted in FIGS. 5 & 6 illustrate that the principles of the invention may be incorporated into a practically unlimited variety of applications.

Referring additionally now to FIG. 5, an apparatus 50 embodying principles of the invention is representatively illustrated. The apparatus 50 includes a generally tubular mandrel 52 and an outer housing 54, with a tube 56 between the mandrel and housing. The housing 54 outwardly protects the tube 56. Such a housing could also be used on the apparatus 30 described above to protect the tube 34.

An upper end 58 of the tube 56 is connected to a line 60 extending to a remote location. A lower end 62 of the tube 56 is open to well fluid external to the apparatus 50 when it is positioned in a wellbore. Alternatively, the lower end 62 could be ported to an interior flow passage of the mandrel 52. Preferably, the tube 56 has a greater internal cross-sectional flow area than the line 60.

When the apparatus 50 is positioned in a sufficiently deviated wellbore, it will be appreciated that the tube 56 will extend alternately upward and downward, that is, in alternating at least partially vertical directions. Thus, the apparatus 50 achieves the benefits of the invention, without having the tube 56 wrapped about the mandrel 52. A flowpath 64 formed through the tube 56 extends alternately upward and downward, thereby forcing any well fluid admitted therein to overcome the force of gravity in order to advance through the tube.

Referring additionally now to FIG. 6, another pressure measurement apparatus 70 is representatively illustrated. The apparatus 70 includes a generally tubular mandrel 72 and a baffled chamber 74. An upper end 86 of the chamber 74 is connected to a line 76 extending to a remote location. A lower end 88 of the chamber 74 is in fluid communication with a flow passage 78 extending longitudinally through the mandrel 72 via a port 80 formed through a sidewall of the mandrel.

The chamber 74 has partitions 82 therein which define a flowpath 84 formed through the chamber from its upper end 86 to its lower end 88. Specifically, the partitions 82 divide the flowpath 84 into alternating upwardly and downwardly extending portions, that is, the flowpath extends in alternating at least partially vertical directions when the apparatus 70 is positioned in a deviated wellbore. Thus, the apparatus 70 achieves the benefits of the invention, without using a tube such as the tube 34 or 56 described above. Instead, the flowpath 84 formed through the chamber 74 extends alternately upward and downward, thereby forcing any well fluid admitted therein to overcome the force of gravity in order to advance through the chamber.

It may be desirable in some situations to maintain a certain vertical relationship of the connection 90 between the line 76 and the chamber 74. For example, to provide enhanced protection against well fluid entering the line 76, it may be desired to maintain the connection 90 in a higher vertical position relative to the chamber 74, or relative to a longitudinal axis 92 of the apparatus 70.

For this purpose, the chamber 74 may be rotationally attached to the mandrel 72, for example, by using bearings 94 at either end 86, 88 of the chamber. This rotational attachment of the chamber 74 to the mandrel 72 permits relative rotation between the chamber and the mandrel. In actual practice, the mandrel 72, interconnected in a tubular string in a wellbore, may rotate within the chamber 74, thereby maintaining a higher vertical position of the connection 90 relative to the remainder of the chamber, or relative to the axis 92.

In the apparatus 30, 50, 70 described above, the flowpaths 48, 64, 84 are positioned external to respective tubular mandrels 32, 52, 72. However, it is to be clearly understood that this relative positioning is not necessary in practicing the principles of the invention. The flowpaths 48, 64, 84 could be positioned entirely or partially internal to the respective mandrels 32, 52, 72. In addition, it is not necessary to use a tubular mandrel at all in practicing the principles of the invention, since other means of conveying the flowpaths 48, 64, 84 into wellbores could be used. Furthermore, although each of the apparatus 30, 50, 70 could be used in place of the prior art apparatus 12 in the method 10, the apparatus 30, 50, 70 may also be used in a wide variety of other methods, in keeping with the principles of the invention.

Referring additionally now to FIG. 7, a method 100 utilizing pressure measurement systems 102 described above is representatively illustrated. The system 102 used in the method 100 may include any of the apparatus 30, 50, 70 described above. In the method 100, the pressure measurement system 102 is positioned in a wellbore 104 which is deviated somewhat past or beyond horizontal (i.e., greater than 90° from vertical).

Prior art pressure measurement systems, such as that depicted in FIGS. 1-3, have been unusable in such a wellbore 104, due to the fact that their chambers would fill with well fluid if they were inclined upward toward their lower ends. However, since the apparatus 30, 50, 70 include respective flowpaths 48, 64, 84 which extend alternately upward and downward, these apparatus may be used in the system 102 in the wellbore 104. This is due to the fact that well fluid must still overcome the force of gravity in order to advance through each of the flowpaths 48, 64, 84, even though lower ends of the apparatus 30, 50, 70 may be inclined upward in the wellbore 104 which is deviated past horizontal.

Referring additionally now to FIGS. 8-10, several embodiments of tubes 110, 120, 130 which may be used for the tubes 34, 56 in the apparatus 30, 50 described above are representatively illustrated. These tubes 110, 120, 130 demonstrate that temperature measurement capabilities may be added to the apparatus 30, 50, and various tube configurations may be used in the apparatus, in keeping with the principles of the invention. It should also be understood that temperature measurement capabilities may also be added to the apparatus 70 in a similar manner.

Temperature measurement in a prior art pressure measurement system has been described in U.S. Patent No. 5,163,321, the entire disclosure of which is incorporated herein by this reference.

In the tube 110, a fiber optic line 112 or optical fiber of the type suitable for temperature measurement is positioned within a flowpath 114 of the tube. The optical fiber 112 may be any conventional optical fiber, such as those used in distributed optical temperature measurement systems. This configuration permits distributed temperature measurements along the lengths of the tubes 34, 56 of the apparatus 30, 50.

In the tube 120, the optical fiber 112 is positioned within a flowpath 122 of the tube, along with thermocouple wires 124. This configuration permits distributed temperature measurements along the lengths of the tubes 34, 56 of

the apparatus 30, 50, with the additional use of a thermocouple (not shown) in the tubes, or beyond the tubes.

In the tube 130, the optical fiber 112 and thermocouple wires 124 are separate from a flowpath 132 extending through the tube. This configuration isolates the optical fiber 112 and thermocouple wires 124 from fluid in the flowpath 132. The optical fiber 112 and thermocouple wires 124 could be isolated from fluid in the flowpaths 114, 122 of the respective tubes 110, 120 using appropriate shielding, coating, casing, etc.

Although only the three alternate embodiments of tubes 110, 120, 130 have been described above, it should be understood that many other tube configurations may be used, without departing from the principles of the invention.

Referring additionally now to FIG. 11, another method 140 embodying principles of the invention is representatively illustrated. The method 140 uses a pressure measurement system 142, which may include any of the apparatus 30, 50, 70 described above. When used in the method 140, however, the respective flowpaths 48, 64, 84 have the optical fiber 112 and/or the thermocouple wires 124 therein as described above for the tubes 110, 120, 130. Thus, the system 142 has the added capability of measuring temperature as well as pressure in a substantially deviated wellbore 144.

In the embodiment of the method 140 illustrated in FIG. 11, this temperature measurement capability is used to detect a gas-liquid interface 146 in the wellbore. Using the optical fiber 112 in, or adjacent to, the respective flowpath 48, 64, 84 of the apparatus 30, 50 or 70, the position of the gas-liquid interface 146 may be relatively accurately determined. The use of one or more thermocouples may provide the same capability of determining the position of the gas-liquid interface along the apparatus 30, 50 or 70.

Of course, a person skilled in the art would, upon a careful consideration of the above description of representative embodiments of the invention, readily appreciate that many modifications, additions, substitutions, deletions, and other

changes may be made to the specific embodiments, and such changes are contemplated by the principles of the present invention. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only, the spirit and scope of the present invention being limited solely by the appended claims and their equivalents.